Compensating Bridge Method for Core-Loss Measurements

THE NATIONAL BUREAU OF STANDARDS has developed a compensating a-c bridge method for the measurement of ferromagnetic core loss at high values of flux density. This method is an improvement over an earlier Bureau-developed technique [1] which made possible the accurate use of an a-c bridge for such measurements but necessitated the use of a "harmonic power" correction term. The recent modification by W. P. Harris and I. L. Cooter of the Bureau's magnetic measurements laboratory eliminates the harmonic power correction, thus simplifying the measurements and calculations involved in loss determinations at high flux densities. [2]

Although cores of ferromagnetic material are essential to the operation of motors, generators, and transformers, the output of such devices is often appreciably lowered by power dissipated in the core due to hysteresis and induced eddy currents. A knowledge of the magnitude of this loss in various materials is necessary for the successful design and efficient utilization of electric equipment.

In using a bridge to make such measurements, the effect of distortion in the current must be considered. At high inductions, the bridge method, as commonly used, always indicates larger power losses than the wattmeter method because of harmonic current components induced by the ferromagnetic core. To obtain the correct result, the power dissipated in the primary circuit at harmonic frequencies must be subtracted from the apparent power dissipated in the ferromagnetic material. Such a calculation involves a tedious and inconvenient determination of harmonic components of power. Therefore, a method of automatic compensation was sought.

Since the "harmonic power" term is equal to $\Sigma I_h^2 R_p$, where I_h is the hth harmonic component in the exciting current and R_p is the resistance in the primary circuit (including the source resistance), it is evident that the correction term would be zero if R_p were reduced to zero. The resistance value of the primary circuit cannot be reduced to zero by ordinary means such as using heavier wire, shorter leads, and lower-valued bridge arms. These elements all contribute some resistance, so that the lowest practicable values of primary resistance are more than 2 ohms in most cases. However, it is possible to add enough negative resistance to make the net primary circuit resistance zero. This was accomplished by using an electronic power source that employs current feedback to produce a negative output resistance. A special circuit was designed so that the magnitude of this negative resistance could be adjusted to counteract the positive resistance.

The accuracy of this method is tested by using a Maxwell-Wien bridge; the unknown arm is an Epstein test frame containing the specimen. For comparison purposes, simultaneous measurements were made with

a sensitive wattmeter. The frequency and specimen size are within the range of the wattmeter. No corrections are made for instrument loss or form factor.

To assure accurate bridge measurements, the effectiveness of the resistance compensation is carefully checked before determining the unknown core resistance in the usual way. The magnitude of the fundamental current is then calculated from an accurate potentiometric measurement of the voltage drop across one of the known resistance arms. From the values of core resistance and current, the power dissipated in the core is directly calculated and compared with the wattmeter readings. Readings made with an average indicating voltmeter allow determination of the flux density at which each set of measurements takes place.
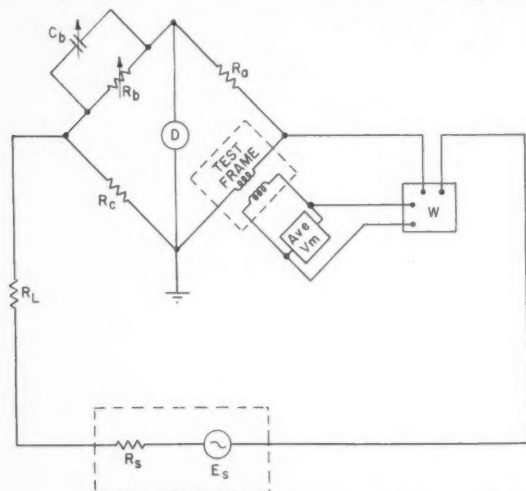
Maxwell-Wien bridge circuit used for measuring core loss at the Bureau. R_l and R_s are the lead and source resistances; R_b and C_b are the balancing resistance and capacitance; D is a tuned detector; and E_s is the input voltage.
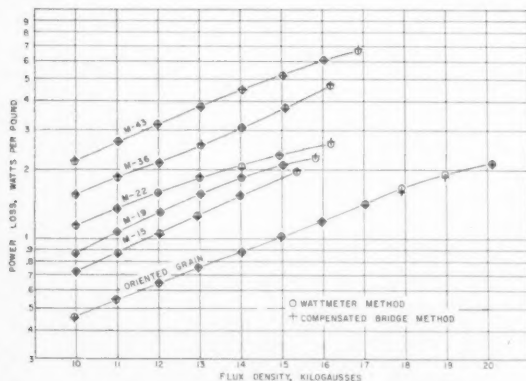
Comparison of results yielded by two methods of measuring power loss in ferromagnetic materials. The losses occurring in six materials at various high-flux densities at 70 cps are shown. The results yielded by the compensated bridge method are indicated by †. Those obtained by the usual wattmeter method are plotted with 0.

Measurements of this kind were made on ferromagnetic specimens weighing approximately 500 g and consisting of strips 3 cm wide and 28 cm or 30.5 cm long. Five grades of nonoriented silicon sheet and one grade of oriented grain material were used for these tests.

The wattmeter and bridge determinations agreed within 2½ percent, even at the highest practical flux densities. The bridge method is expected to be especially useful at high frequencies and for small test samples where accurate wattmeter readings cannot be obtained.

TABLE 1. *Typical results of core-loss measurement with wattmeter and compensated bridge* [a]

B	Bridge	Power Loss (w/lb)	Percentage difference
Kilogausses		*w m*	%
10. 00	0. 866	0. 869	−0. 3
11. 00	1. 060	1. 060	. 0
12. 02	1. 293	1. 294	−. 1
13. 00	1. 553	1. 560	−. 4
14. 01	1. 835	1. 848	−. 7
15. 03	2. 094	2. 096	−. 1
15. 83	2. 299	2. 257	+1. 9

[a] These results were obtained at 70 cps with a nonoriented grain sample weighing 0.744 lb.

[1] Measurement of ferromagnetic core losses at high flux densities, NBS Tech. News Bul. **41**, 60 (April 1957); Investigation of an alternating-current bridge for the measurement of core losses in ferromagnetic materials at high flux densities, by *Irvin L. Cooter and William P. Harris, J. Research NBS* **57**, 103 (August 1956) RP2699.

[2] Improved bridge method flux densities, by *William P. Harris and Irvin L. Cooter, J. Research NBS* **60** (May 1958) RP2865.
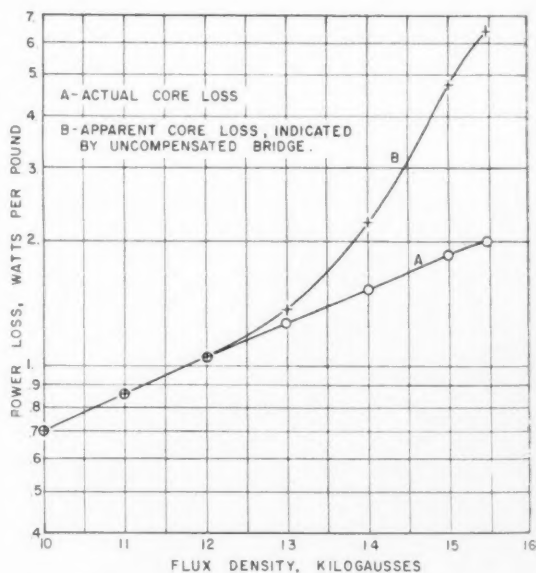
Graph showing the discrepancy between the actual power loss in a ferromagnetic material as measured by the compensated bridge and the loss measured by an uncompensated bridge at high-flux densities.

Cathodic Protection of Steel in Salt Water

THE NATIONAL BUREAU OF STANDARDS has completed a study of the electric potential needed to protect steel cathodically from corrosion in salt water. Data obtained under controlled laboratory conditions are expected to provide a basis for handling similar problems encountered under marine conditions.[1] It was found that the best degree of protection was achieved when the specimens were held at −0.77 v with reference to a saturated calomel electrode.

Normal corrosion of iron and steel is an electrochemical phenomenon. When metal is exposed to salt water, differences in electric potential develop at the surface of the metal, resulting in the formation of numerous small corrosion cells. This action causes destructive alteration of areas, known as anodes, on the metal surface where metallic ions enter the electrolyte. In applying cathodic protection, direct current from an external source is caused to flow from an auxiliary anode toward the corroding surface. This prevents positive metal ions from entering the electrolyte.

The potential at which a metal structure should be maintained in order to prevent corrosion is a question of practical interest. Insufficient negative potential will give inadequate protection. On the other hand, maintaining a greater potential than is needed is unnecessarily costly. Some engineers are of the opinion that −0.85 v with reference to a copper—copper sulphate electrode (equivalent to −0.77 v with reference to a saturated calomel electrode) sometimes represents overprotection and excessive current demands. It was to study this problem that W. J. Schwerdtfeger of the Bureau's corrosion laboratory undertook the present work.

An earlier laboratory investigation of corrosion in various types of soils using soil cells had shown that steel specimens maintained at −0.77 v with reference to a saturated calomel electrode lost negligible weight in a 60-day exposure period. Also, deviations in potential electropositive to this voltage for relatively short intervals resulted in appreciable weight loss. Specimens maintained at more negative potentials (−1.0 v) generally showed no greater reduction in weight loss.[2]

The corrosive environment chosen for the present study was Washington (D. C.) tap water with an added 3 percent by weight of sodium chloride. This electrolyte presented no problem in the measurement of sig-
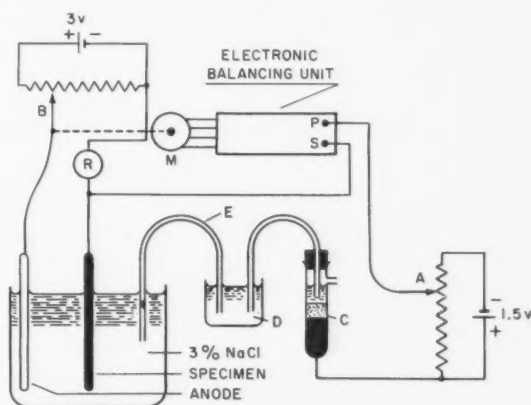
Diagram of circuit that controls potential to within ±5 mv of the adjusted value. *A* and *B*, voltage dividers; *C*, electrode; *D*, container of saturated potassium chloride; *E*, agar-salt bridge; *M*, motor; *P* and *S*, terminals. When specimens are protected at a designated potential, the polarizing current is continuously recorded by a strip chart recorder, *R*.

nificant potentials; no special equipment was needed as the *IR* (voltage) drops in the salt water were negligible. All specimens were 16-in. long, 0.5-in. diameter, cold-rolled steel rods, taped at the water line, and suspended vertically in the water for 60 days.

Currents and potentials were measured with both recording- and indicating-type instruments. Protective potentials were controlled to within ±5 mv by an electronic balancing unit which actuated a motor-driven voltage divider that applied current to the specimens. Currents required to maintain these potentials were compared with the currents indicated by changes-in-slope, referred to as "breaks", of cathodic polarization curves obtained on control specimens. The polarization curves were obtained automatically by using a synchronously driven voltage divider and a two-pen (current and potential) recorder.

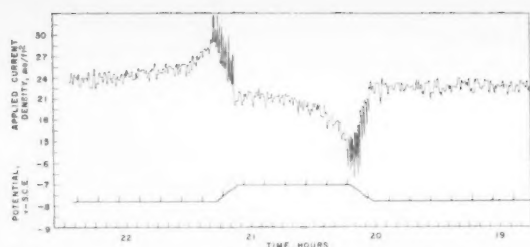Under both stagnant and aerated exposure condi-

Wooden vat used at the Bureau to expose steel specimens to a salt-water environment. Here one end of a flexible agar-salt bridge, connected to a reference electrode at the other end, is being inserted through an insulated sleeve into the water.

Recorded variation of the cathodic current density of a steel specimen. The potential of the specimen (with reference to a saturated calomel electrode) was varied from −0.77 v after 20 hr to 0.70 v, and then back to −0.77 v.

tions, the best degree of cathodic protection was attained at −0.77 v with reference to a saturated calomel electrode. Although a good (but lesser) degree of protection was noted at potentials more noble than −0.77 v, this degree of protection could not be obtained at lower current densities. Therefore, −0.77 v was considered to be the optimum protective potential.

It was found that the applied currents indicated by the breaks in cathodic polarization curves agreed reasonably well with the currents required to maintain polarization at −0.77 v. The break current, which also was observed to be related to the corrosion current itself, is therefore considered to be a good measure of the current required for optimum protection. In some of the experiments, a short preliminary period of exposure without protective current greatly reduced the amount of current initially required for cathodic protection.

[1] For further technical details, see Current and potential relations for the cathodic protection of steel in salt water, by W. J. Schwerdtfeger, J. Research NBS **60**, 153 (1958) RP2833.

[2] Potential and current requirements for the cathodic protection of steel in soils, by W. J. Schwerdtfeger and O. N. McDorman, J. Research NBS **47**, 104 (1951) RP2233.

Low-Temperature Strength of Epoxy-Resin Adhesives

RECENT EXPERIMENTS at the Boulder Laboratories of the National Bureau of Standards sponsored by the Atomic Energy Commission show that several filled epoxy resins, already known to be effective metal adhesives at normal temperatures, exhibit considerable strength when cooled to 20°K (−253°C).[1] Primarily an evaluation of the mechanical strength of copper bonds, the investigation was undertaken by R. M. McClintock and M. J. Hiza of the Bureau Cryogenic Engineering Laboratory to provide design information for a liquid hydrogen cooled electromagnet.

As a result of an earlier search for an adhesive useable at temperatures as low as 4°K, it was proposed that the adjacent coils of this high field solenoid be spaced with an epoxy-resin adhesive to provide structural rigidity as well as electrical insulation at the operating temperature of 20°K. It was therefore necessary to verify the assumption that the bond would not be seriously harmed by the conditions under which the electromagnet will operate.

The adhesives studied were two component systems consisting of a liquid organic amine curing agent (diethylaminopropylamine) and an epoxy-resin paste containing an inorganic filler, predominantly alumina in one, and asbestos in another. The recently developed "epoxy resins" are a series of polymers, each capable of reaction with many curing agents, and with possibly quite different properties. Consequently, while the results of these experiments are thought to be indicative of how most epoxy-resin adhesives would perform, they are only known to be valid for the few tested.

Six Experiments

Six groups of experiments were performed: (1) The impact strength of the cured adhesive in bulk was measured at 300°K and 76°K; (2) the thermal expansion of the cured adhesive between 76°K and 300°K was measured; (3) the tensile and shear strengths of copper bonds were measured at 300°, 76°, and 20°K with rapid cooling to these lower temperatures; and, using room temperature tensile and shear strengths as indices, the effects of (4) exposure to high temperatures, (5) exposure to low temperatures, and (6) adhesive thickness, were determined. Impact tests were performed on notched and unnotched specimens at both 300°K and 76°K. Actually the strength observed for the notched specimens at 300°K and 76°K and for the unnotched specimens at 76°K was so low that the kinetic energy imparted to the broken pieces accounted for the major portion of the indicated strength. This was eliminated from the results by replacing the broken ends in the machine and noting the energy required to accelerate them by the swinging pendulum. The
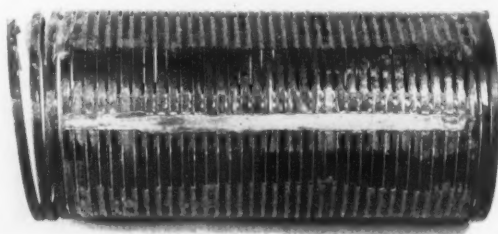
High-field solenoid with copper turns bonded with an alumina-filled epoxy-resin adhesive whose low-temperature strength was studied by the Bureau. The coil is part of an electromagnet designed by Los Alamos Scientific Laboratory.

values obtained are perhaps accurate to only 50 percent, but they do show notch sensitivity of the material as well as increased brittleness with decreasing temperature.

The tensile and shear specimens were designed to approximate the geometry and material of the proposed magnet coil. This allowed information to be obtained on optimum design characteristics for the specific application in view as well as on basic epoxy-resin properties relevant to low-temperature applications generally.
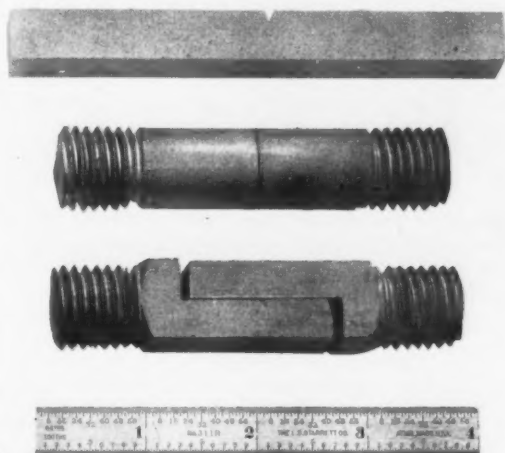
Specimens (*top to bottom*) for impact, tensile, and shear experiments on epoxy-resin adhesives.

Results

The mode of failure in the case of the tensile specimens was cohesive near the center of the glue line. As the exposure temperature increased, these specimens showed a change in mode of failure from cohesion to what was apparently a failure of the bond between the metal and adhesive with an accompanying decrease in tensile strength. Without exception, the shear specimens failed in such a way as to leave the entire thickness of adhesive on one-half of the specimen in any given local area.

It was first suspected that the molecular bond between metal and adhesive was weaker in shear than the adhesive itself. However, small metal fragments were often torn from the copper surfaces by the adhesives. This suggests that the bond between metal and adhesive may possibly be strong enough for fracture to occur in the body of the adhesive, leaving at least a monomolecular layer of adhesive on one metal surface. Since thermal stresses in the adhesive are a maximum near the interface and decrease toward the center of the adhesive layer, a superimposed mechani-

cal shear stress should produce failure in a plane very near the interface. Such thermal stresses exist, of course, even at room temperature if the adhesive has been cured at an elevated temperature; and the obvious remedy is to match thermal expansion of the cured adhesive with that of the metal. For the adhesives studied, the filled resins contracted about half as much between 300° and 76°K as the unfilled resin and about twice as much as the copper to which they were bonded.

Bonds tested at 20° and 76°K after rapid cooling displayed roughly the same tensile strength as at room temperature, but showed a considerable decrease in shear strength, approximately 50 percent, at the low temperatures. There was no significant change in shear strength between 76° and 20°K. Rapid thermal cycling between 76°K and room temperature prior
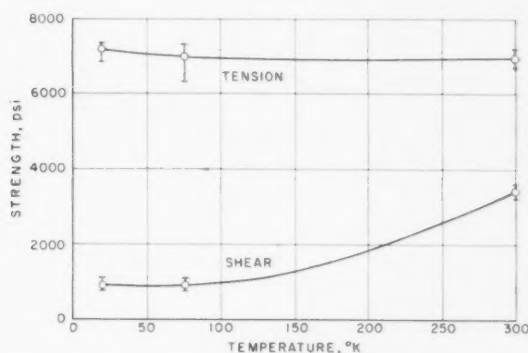
Strength of a filled epoxy-resin adhesive bond at temperatures from 20°K to 300°K.

to room temperature tests, produced a decrease in shear strength of about the same magnitude as that of 76°K tests, but the tensile strength was only slightly affected. Exposure temperatures above the cure temperature, 200°F, caused damage to the bonds and resulted in decreased tensile and shear strengths. These bonds were seriously harmed by temperatures of 398°K (125°C) and higher. Thickness of the adhesive bond was found to have no noticeable effect on strength between 0.010 and 0.030 in.

A coil for a high field solenoid has been fabricated at the Los Alamos Scientific Laboratory with 1/8-in. square copper wire bonded with an alumina-filled epoxy-resin adhesive. This coil has withstood repeated cycling between room and liquid nitrogen temperatures, but has not yet been used to produce a magnetic field.[2]

[1] *For further technical information, see* Epoxy resins as cryogenic structural adhesives, *by R. M. McClintock and M. J. Hiza, Proceedings of the 1957 Cryogenic Engineering Conference, edited by Dr. K. D. Timmerhaus, Colorado University, Boulder, Colorado.*
[2] *Private communication from H. L. Laquer, Los Alamos Scientific Laboratory (December 3, 1957).*

Studies of Electroless Plating

INCREASED UNDERSTANDING of the conditions favoring "electroless plating" has resulted from recent research at the National Bureau of Standards. This chemical deposition process [1] for plating nickel and cobalt on metal surfaces, was developed a decade ago by the Bureau. It is similar in many respects to electroplating but does not employ an electric current. Although adapted by a number of industries for specific applications, electroless plating has not been systematically studied to any great extent. Thus, to obtain further information on the nature of the deposition, C. de Minjer [2] and A. Brenner of the Bureau's electrodeposition laboratory have been investigating the variables that effect the rate of nickel plating and the degree of protection that the coating provides. [3]

Unlike electrodeposition, electroless plating can be used to build up smooth, uniform coatings to a definite thickness over irregularly shaped objects without producing nodular deposits on edges and corners. In other chemical processes for metallic films, the depositing metal is randomly distributed over the container walls as well as over the objects immersed in the solution. Also, after several minutes, the reaction runs to an end and the exhausted solution must be discarded.

The effect of weathering on electroless nickel plating as compared to other types of nickel-coated steels. The electroless nickel plate (b) and the electrodeposited nickel coat with 9-percent phosphorus (c) withstood the 15-month exposure with very little corroding. However, the electrodeposited sample (a) rusted markedly.

With the electroless process, however, a nickel coating is deposited only on certain catalytic metals, such as iron, nickel, cobalt, and palladium; deposition does not occur elsewhere in the bath. Furthermore, by periodically replenishing the bath with the appropriate chemicals, the system can be run continuously for hours or even days. Since the reaction is autocatalytic, that is, the nickel itself catalyzes the process, the deposition continues once a nickel surface is obtained on any object. Noncatalytic metals can be made catalytic by immersion in a dilute solution of palladium chloride, which coats the metal surface with an almost invisible film of catalytic palladium.

Electroless nickel deposits are not pure nickel but consist of a nickel phosphorus alloy containing about 8-percent phosphorus. The deposits are bright and much harder than pure nickel deposits.

The electroless process involves the reduction of hot nickel salt solutions, such as the chloride or sulfate, with pure sodium hypophosphite. An organic acid, such as glycolic or citric acid, is added to the bath as a combined buffering and complexing agent. Actually the reaction utilizes only about one-third of the hypophosphite reducing power because a concurrent reaction between the hypophosphite and water produces hydrogen and phosphite.

Experiments were conducted on the rate of deposition at various values of pH. The originally developed electroless bath deposited coatings at the rate of only a few tenths of a mil per hour and rates of the order of 1 mil per hour were desirable. Although the acidity increases during operation of the bath, it was not feasible to control the pH during the plating. Instead, a relatively large volume of the bath (1 liter), was used to plate a relatively small specimen (having an area of only 12 cm^2). Under these conditions, the change in hydrogen ion concentration was not significant.

An increase in the acidity of the bath considerably reduced the rate of plating. For example, a decrease in the pH of the bath from 5 to 4 halved the rate. Ordinarily a higher pH could be maintained by continually adding alkali, but the upper value of the pH is limited by the precipitation of nickel phosphite. This reaction is undesirable because the presence of a precipitate leads to spontaneous decomposition of the bath. Thus, the optimum pH of the electroless bath is limited at the lower level by the decrease in the rate of nickel deposition and at the higher level by the diminishing solubility of nickel phosphite. The most satisfactory pH for the acid bath was found to be between 4 and 4.5.

The organic acids used for the buffering and complexing in the baths were found to have specific effects on the rate of deposition. Hydroxyacetic (glycolic) acid yielded a higher rate of deposition than most of the other acids, with the exception of lactic acid. However, the lactic acid bath was not as stable and produced rougher deposits. The rate of deposition reached a maximum at a specific concentration for each acid. Since the acids do not change the chemistry of the reaction, they may influence the rate through adsorption on the active nickel surface. Thus the maximum in the rate curve can be explained on the basis that a low adsorption of the acid accelerates the reaction while a high adsorption poisons the catalytic surface.

Several hypotheses have been suggested to explain the electroless plating mechanism. The suggested

theory involves a two-step process. In the first step, hypophosphite is catalytically decomposed to release hydrogen. In the second step, energy liberated in the discharge of hydrogen is transferred to the nickel ion, and activates the latter so that it can react with the hypophosphite ion. The nature and rate of hydrogen release determine the rate and efficiency of the nickel deposition. The hydrogen overvoltage on a metal surface may be taken as a measure of the ease of hydrogen liberation on the surface. A low overvoltage should
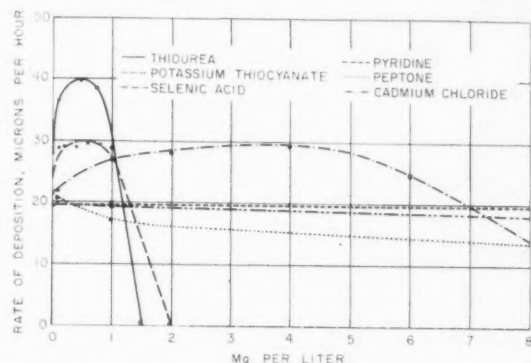
Graph showing the influence of various substances on the rate of electroless nickel plating. These compounds, which normally inhibit the chemical reaction accelerate the process when added in minute quantities.

facilitate the discharge; however, the energy for activating the nickel ion would also be low. The hydrogen should possess more energy for activation if released from a high-overvoltage surface, but its discharge would occur less readily. Consequently, some intermediate overvoltage should be the optimum for the deposition of nickel.

The suggestion that there should be a correlation between overvoltage and rate of plating led to a study of the influence of certain reagents on electroless plating. Although the correlation between overvoltage and the plating rate was not actually established, it was found that small concentrations of certain addition agents appreciably increased the rate, slightly higher concentrations decreased the rate, while still higher concentrations prevented deposition. Certain substances, classified as catalytic poisons, in concentrations of about 1 part per million of solution, markedly raised the rate of deposition. As with organic acids, the effect of these substances reached a maximum at a certain concentration. Thiourea and potassium thiocyanate gave the most significant effect. The former greatly increased the rate of deposition, producing a noticeable effect even in a concentration as small as 0.1 mg/liter. As yet, it has not been determined whether these additives can be used in practical plating operations.

Outdoor exposure tests were made of plated steels to compare the protective value of electroless nickel deposits with that of electrodeposited nickel and nickel-phosphorus alloys. Samples were prepared from both acid and alkaline types of electroless baths. Results showed that electroless nickel coatings—from acid baths—offered steel greater protection against rusting than did electrodeposited coatings. Although somewhat tarnished, the electroless plates had only a few rust spots at the end of a 15-month period, while the electrodeposited nickel of the same thickness and under the same conditions rusted considerably. The protective value of the electroless nickel deposits was equivalent to that of the electrodeposited phosphorus alloys which contained about 9-percent phosphorus.

[1] Electroless plating on metals by chemical reduction, *NBS Tech. News Bul.* **31**, *111* (1957).
[2] *Present address: Philips Research Laboratory, Kanstanje Laan, Eidhoven, Holland.*
[3] *For further technical information, see* Studies on electroless nickel plating, *by C. de Minjer and A. Brenner, Plating* **44**, *1297* (1957).

Matrix Manipulator

IN COMPUTATION involving matrices it is frequently necessary to interchange or rearrange rows or columns of a matrix. If the work is being done in longhand or with a desk calculator, it is desirable to be able to perform the rearrangements without having to erase or rewrite numbers. A simple mechanical matrix manipulator which achieves this result has been designed by D. M. Mesner of the Bureau. The possibility of designing a desk-size electronic instrument to perform the same operations is being considered.

The matrix manipulator was devised for use in the Bureau's Statistical Engineering Laboratory for calculations with incidence matrices, i. e., matrices whose elements are all zeros or ones. Matrices of this kind arise in many branches of science and pure mathematics, as well as in statistical analysis. The solution of

systems of linear equations, perhaps the best known application of matrices, should also be facilitated by the manipulator.

The device consists of a set of small plastic blocks which can be arranged in a rectangular array to serve as cells of a matrix. The upper faces are sanded to provide writing surfaces for pencil or pen. The blocks are drilled with two horizontal holes each, through which a metal rod can be passed, so that an entire row or column can be lifted out and replaced where desired.

If arithmetical operations result in new numbers in the matrix, the old numbers can be erased and the new ones put in their place about as easily as on paper. The blocks could also be replaced by others containing the new numbers. When working with incidence matrices, where only zeros and ones occur, the matrix

pattern can be more easily distinguished if the ones are represented by blocks with a black top while the zeros are left white.
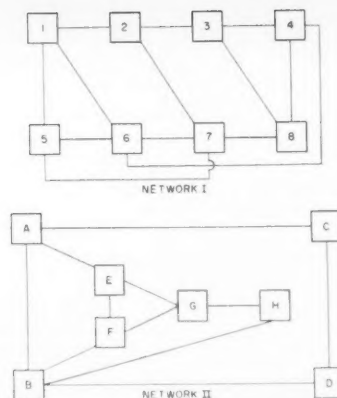
Comparing Networks

A good illustration of a problem which can be solved by rearranging rows and columns of a matrix is that of determining whether or not two networks have the same structure. An example is shown in the figure which gives the diagrams of two networks, each containing eight boxes connected by lines. If the lines are interpreted as the appropriate form of connection or communication, then such networks might represent the connections in an electrical circuit, the flow of in-

Matrix manipulator for quick rearrangement of rows and columns of a matrix. An entire row or column can be lifted out with a metal rod that is passed through holes in the plastic blocks that represent matrix cells. Here two 8×8 incidence matrices, representing two networks, are being compared; blacktopped blocks stand for ones and white blocks for zeros.

formation between components in a computer, the channels of communication between departments of an organization, or the structural formula of a molecule, to mention a few of the possibilities. Whatever the interpretation of the diagram, any network can be represented in concise mathematical form by an incidence matrix with rows and columns labeled to correspond with the boxes. In such a matrix, the entry in position x of row y is set equal to one if boxes x and y are directly connected, or it is set equal to zero if the same boxes are not so connected. The incidence matrices for networks I and II are given in table 1.

Suppose it is desired to know whether the two networks are as different as they appear, or whether they really have the same structure and differ only in the way the diagrams have been arranged on the paper. Put in another way, the problem is to find whether the boxes of network II can be relabled with the numbers one to eight in such a way that the pairs of boxes di-

Schematic diagrams of 2 networks whose comparison is facilitated by use of the matrix manipulator. The networks might be interpreted, for example, as showing the flow of information betwen components of a computer. Each is represented by an incidence matrix (see table); if the matrices can be brought to a common form by rearranging rows and columns (subject to certain simple conditions) the circuits are identical in structure though appearing very different. Thus, the two networks illustrated have the same structure.

rectly connected by lines in network II have exactly the same numbers as the connected pairs in network I— and vice versa.

However, renumbering the boxes of a network in a different order has exactly the same effect as rearranging the rows and columns of the incidence matrix in the corresponding order. Thus the networks are identical if we can find a rearrangement (permutation) of the rows and columns of the second matrix which will give it exactly the same pattern of ones and zeros as the first matrix.

The matrix manipulator makes it easy to try different arrangements. In working with an 8×8 matrix, an extra row and an extra column are added for carry-

TABLE 1. *Incidence matrices*

				Network I				
	1	2	3	4	5	6	7	8
1	0	1	0	0	1	1	0	0
2	1	0	1	0	0	0	0	1
3	0	1	0	1	0	0	0	1
4	0	0	1	0	0	0	1	0
5	1	0	0	0	0	1	1	0
6	1	0	0	1	1	0	1	0
7	0	1	0	0	1	1	0	1
8	0	0	1	1	0	0	1	0

				Network II				
	A	B	C	D	E	F	G	H
A	0	1	1	0	1	0	0	0
B	1	0	0	1	0	1	0	1
C	1	0	0	1	0	0	0	1
D	0	1	1	0	0	0	0	1
E	1	0	0	0	0	1	1	0
F	0	1	0	0	1	0	1	0
G	0	0	0	0	1	1	0	1
H	0	1	1	1	0	0	1	0

ing the numbers or letters that index the rows and columns; the index row and column furnish a record of the rearrangement that has been carried out and provide a check that the same rearrangement has been used for rows as for columns.

In practice, it is convenient to set up both matrices on blocks and try to rearrange each of them into a common form. In the example of networks I and II,

it is helpful to begin by placing the two rows that contain four ones in leading position, then doing the same for the columns. A few trials are sufficient to find rearrangements that make the matrices identical, showing that the two networks do indeed have the same structure. When the matrix for network I is left unchanged, the rearrangement found for network II and its incidence matrix is: C A E G D H B F.

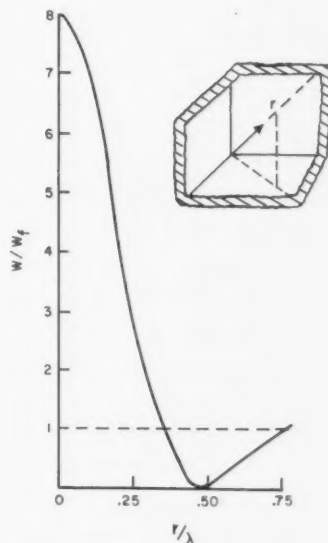# The Sound Output of a Source in a Reflecting Environment

FOR MANY YEARS the Bureau has been making standard acoustical measurements and working on the development of new standards in the field of sound. Recent work in this area has included an investigation of a standard method of measuring sound-power output. Such a standard would be useful for measuring the output of technical apparatus such as loud speakers and transformers, and for specifying the output of household appliances such as fans and refrigerators.

One useful method of measuring the sound-power output of a source is the reverberation-chamber method. R. V. Waterhouse of the Bureau's sound laboratories has investigated the accuracy of this method [1] and its suitability for standardization. Although it gives less accurate results than measurements made in an anechoic (nonreflecting) environment, the reverberation-chamber method has other advantages to recommend it: A reflecting room is less expensive to build than an anechoic chamber, and is more suitable for large sound sources, such as automobiles.

The reverberation method relies on the fact that in a room whose walls are highly reflecting to sound, the sound field approaches a uniform energy density, proportional to the sound-power output to be measured. However, the source may emit more sound in the reverberation chamber, owing to the reflected impedance of the walls of the chamber, than it would in a free field. In the Bureau's work the reflected impedance, and hence the power output, was calculated for certain types of source as a function of position in a reverberation chamber. From these results estimates can be made for the variations in the sound output of sources with environment.

One such estimate has been made for a source radiating sound evenly in all directions. The output of this type of source will generally vary less than 1 db (or about 25%) from the free-field value if two conditions are fulfilled. The first is that the source be at least a wavelength away from all reflecting surfaces, and the second is that the room surfaces absorb at least 3 percent of the incident sound energy.

In a rectangular room, the output of this type of source varies greatly with position near a reflecting corner. The output may either be much increased or much decreased with respect to the free-field value, depending on its distance from the corner. When that

Theoretical curve showing how the power output of a point sound source placed near a reflecting corner varies with position. As the source is moved along the line of symmetry, a distance r, as shown in insert, from the corner, the output W is alternately decreased and increased with respect to the free-field value, W_f.

distance is small compared to the wavelength of the sound emitted, the power output is about eight times the free-field value. When the distance becomes as large as half a wavelength, the power drops to less than one-tenth that in a free field.

To check these theoretical predictions, a signal at a frequency of 350 cps was applied to a small loudspeaker in a box. The wavelength was about six times the box dimension, and a curve similar to the one discussed above was obtained. Although most sound sources are more complicated than the one used, most sources would give the same kind of effect.

[1] The output of a sound source in a reverberation chamber and other reflecting environments, by R. V. Waterhouse, J. Acoust. Soc. Am. **30**, 4 (January 1958).

Thin-Target Bremsstrahlung Experiments

BREMSSTRAHLUNG—THE X-RADIATION produced when electrons are decelerated in the coulomb field of atomic nuclei—is currently being investigated by the radiation physics laboratory of the National Bureau of Standards. This study is part of a basic research program carried on over the past 25 years which is concerned with the production and interaction of X-rays in matter and the development of X-ray standards.

The X-rays produced in the bremsstrahlung process have become a basic tool in modern science and technology. They find diagnostic applications in medicine and dentistry, provide industry with radiographic methods for examining metal objects, and aid scientists in studying the structure of matter. Also, they provide information about the interaction processes of elementary particles. They are presently playing an essential role in defining the conditions under which the thermonuclear reactor—power source of the future—will operate.

In the bremsstrahlung process, an atomic target is bombarded with electrons. The electrons interact with the target nuclei, causing X-ray photons to be emitted. These photons have a certain energy and angular distribution and certain polarization properties. The bombarding electrons continue on their way with diminished energy and altered direction. The final energy of each electron is the residual energy in a specific bremsstrahlung process. The angular distribution of the electrons is correlated with photon energy and angle.

Since no one mathematical theory adequately explains the process, the Bureau undertook the present work to provide an understanding of the characteristics of X-rays produced in this way. The goal of the study is to obtain detailed experimental data on the bremsstrahlung process which can be used to describe radiation under any set of experimental conditions and to check theoretical calculations. Such data will also provide a greater understanding of other quantum electrodynamic processes, such as pair production, which are similar to bremsstrahlung.

Before this study began, little experimental information about the bremsstrahlung process was available. For example, very few absolute measurements had been

TABLE 1. *NBS Bremsstrahlung Measurements (Thin-Target Experiments)*

Electron energy	Electron source	Characteristic measured	Measurement technique
50 kev	Constant-potential accelerator	X-ray spectra and angular distribution	Sodium iodide spectrometer.
0.5 and 1 Mev	Constant-potential accelerator	X-ray spectra and angular distribution	Sodium iodide spectrometer.
0.5 and 1 Mev	Constant-potential accelerator	X-ray polarization	Compton crystal-polarimeter.
2.7, 4.5, and 9.7 Mev	50-Mev betatron	X-ray spectra and angular distribution	Sodium iodide spectrometer.
15 Mev	50-Mev betatron	High-energy end of spectrum	15.11-Mev level in C^{12} nucleus.

made to determine the cross section (probability of the process occurring) for a given target nucleus. Experiments were primarily confined to thick targets, and were concerned with the total energy flux density at a given distance from the target or with the relative energy and angular distribution of the X-rays. Since the basic bremsstrahlung process results from an interaction between one electron and one nucleus, results for thick targets where many electrons interact with many nuclei are difficult to interpret as a consistent, accurate theory for the production of X-rays.

In the current study, the Bureau has been investigating the production of X-rays in thin targets as a function of the various parameters involved in the bremsstrahlung process—such as the initial electron energy, the photon energy and emission angle, the photon polarization, and the electron recoil energy and angle.

In this work electrons are accelerated by two constant-potential devices operating in the energy range from 50 to 1,400 kev and by a 50-Mev betatron. Measurements have been carried out over the range from 0.05 to 15 Mev by various experimental methods. Low-energy bremsstrahlung studies (0 to 1 Mev) were carried out by J. W. Motz and coworkers of the Bureau's X-ray Laboratory, and high-energy studies (2 to 50 Mev) were carried out by H. W. Koch and coworkers of the Betatron Laboratory.

The results of these measurements differ significantly with the predictions of available theories. This dis-

Artist's conception of the bremsstrahlung process. Electrons are shown coming from the left and impinging on a portion of a thin-foil target. As the electrons strike atoms in the target X-rays are emitted with specific energies and directions. The original electrons continue on their way with altered directions and reduced energy.
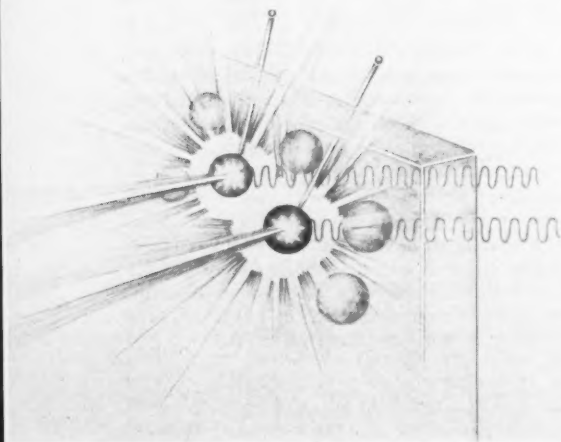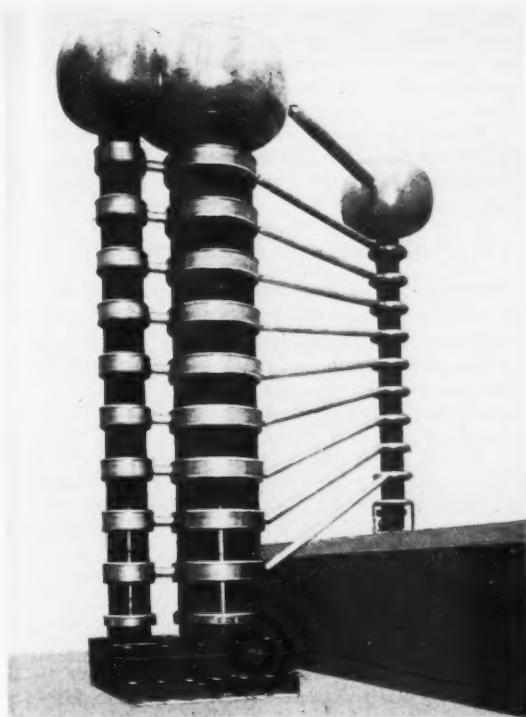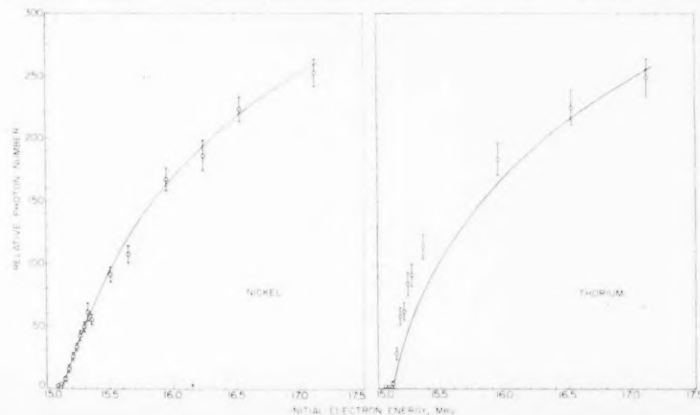
Constant-potential X-ray accelerator used in low-energy bremsstrahlung experiments at the Bureau.

crepancy forces the scientist to depend mainly on the experimental picture, emphasizing the need for a more exact theory. In general, the disagreement between the theory and measurements becomes more pronounced as (a) the atomic number of the target increases, (b) the photon energies increase toward the upper limit, and (c) the electron energies decrease.

Low-Energy Measurements

Several experiments were conducted at energies below 2 Mev using a constant-potential accelerator as an electron source. At electron energies of 0.05, 0.5, and 1 Mev the X-ray spectra and angular distribution of photons were obtained with a scintillation spectrometer, consisting of a sodium iodide crystal, photomultiplier, and pulse-height analyzer.[1,2] The bremsstrahlung differential cross section was determined directly from the experimental data and compared with theoretical estimates of the cross section. Experimental points were found to differ from theoretical values by a factor as great as 2.
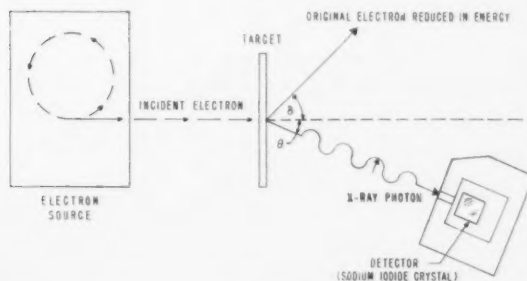
An electron beam is shown impinging on a thin target. The incident electron continues on its way with altered directions (δ) and reduced energy after the impact. The target atom involved in the collision emits an X-ray photon which is detected by a sodium iodide crystal. As well as a specific energy and direction (Θ) the emitted photon has certain polarization properties ($\uparrow$).
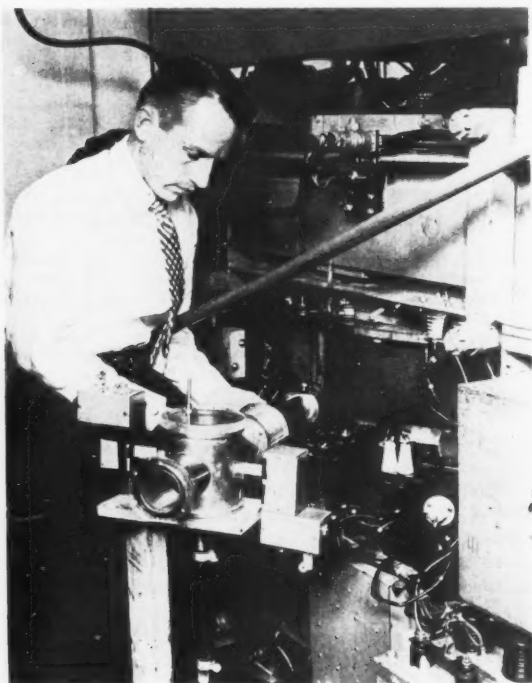
High-Energy Measurements

In the experiments with betatron-produced electrons having energies greater than 2 Mev,[3,4] both the general shape of the X-ray spectra and the shape of the high-energy tip were observed. These measurements showed excellent agreement with theory in the general shape of the spectra and absolute magnitude of the cross section. However, the factor of 2 which characterizes the departure of experimental results from theory at low energies (below 1 Mev) was also present for certain high-energy measurements. This discrepancy occurred for targets of high atomic number at the high-
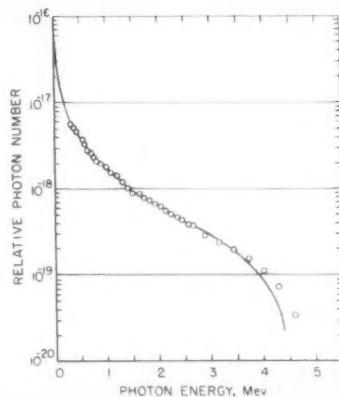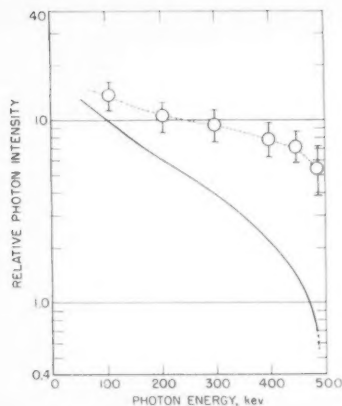

An investigation of the high-energy tip of bremsstrahlung spectra reveals that in the last 0.2 Mev of 15-Mev to 20-Mev spectra from a thorium target almost twice as many photons are produced (experimental points) as are predicted (solid line). The result for a nickel target shows excellent agreement between the experimental points and the theoretical curve.

energy end of the spectrum, where the outgoing electron energy is small.

To obtain an experimental picture of the way in which the bremsstrahlung spectrum trails off at its high-energy end, the Bureau utilized the fine energy resolution inherent in the process of photoexcitation. In examining the high-energy end of 15- to 20-Mev spectra, the photoexcitation of the 15.11-Mev level of carbon-12 was used. The scattering produced by incident bremsstrahlung indicates the number of bremsstrahlung photons in the narrow energy band which produced photoexcitation. The width of this band is

The 50-Mev betatron used as a source of high-energy electrons in bremsstrahlung experiments at the Bureau.

only 15.11 ±0.000040 Mev—a great improvement in energy resolution over the resolution of 15.11 ±.5 Mev allowed by spectrometric methods. It was found experimentally with this good resolution that there are almost twice as many photons in the last 0.2 Mev of this spectrum as predicted by theory. This result is of significance in photonuclear research performed with a betatron X-ray source as well as in bremsstrahlung investigations.

Polarization Measurements

Another type of experiment was conducted on 0.5- and 1-Mev bremsstrahlung radiation.[5] An X-ray polarimeter was constructed which was used to measure the photon polarization as a function of photon energy and angle. Results show that the behavior of X-ray polarization is considerably different from theoretical estimates. For example, with 1-Mev electrons and a gold target, the polarization reversal occurs at a lower photon energy than predicted, and with 0.5-Mev electrons, the polarization for small photon emission angles is smaller by a factor of 2 than the theoretical predictions.

Other experiments are planned to measure the angular distribution of a recoil electron associated with photons having a particular energy and emission angle. Dependence of photon polarization on initial electron energy will also be investigated. These experiments will provide basic data needed for a complete quantitative description of the bremsstrahlung process.

[1] Bremsstrahlung cross-section measurements for 50-kev electron, by J. W. Motz and R. C. Placious, Phys. Rev. 102, 235.

[2] Bremsstrahlung differential cross-section measurements for 0.5 and 1.0 Mev electrons, by J. W. Motz, Phys. Rev. 100, 1560.

[3] Differential cross-section measurements of thin-target bremsstrahlung produced by 2.7 to 9.7 Mev electrons, by N. Starfelt and H. W. Koch, Phys. Rev. 102, 1598.

[4] Shape of the high-energy end of the electron-bremsstrahlung spectrum, by E. G. Fuller, E. Hayward, and H. W. Koch, Phys. Rev. 109, 630.

[5] Bremsstrahlung polarization measurements for 1.0 Mev electrons, by J. W. Motz, Phys. Rev. 104, 557.

The Bureau found bremsstrahlung spectra produced by 500-kev electrons (left) in a gold target (experimental points) to differ significantly from theoretical predictions (solid line). X-ray bremsstrahlung spectra from a gold target for high-energy electrons (right) show excellent agreement between theory (solid line) and experiment (points) except at the high-energy end of the spectrum.

Surface Attack by Buffer Solutions

GLASS, like metal, undergoes a corrosion process when partially immersed in certain solutions. Both glass and metal may also be attacked much more severely at the liquid air interface than in the bulk volume when immersed in the liquid. Experiments performed at the Bureau by R. G. Pike and D. Hubbard have demonstrated that the attack on glass at the surface of a solution at pH 7.0 is equal to the bulk volume attack in a solution at pH 9.4.[1] This finding is of value in understanding the mechanical weakening of glassy materials at the boundary of an aqueous solution.

An interferometer was used to measure the attack on a glass composed of soda, lime, and silica at the eutectic composition. Specimens were ground and polished to optical flatness and then partially immersed in the attacking solution for a definite period of time

Interferometric patterns obtained at the Bureau in a study of liquid-line attack on glass. Glass samples were exposed at 80° C for 6 hr. Patterns obtained at various pH's indicated the following effects: (A) At pH 4 swelling of the specimen; (B) at pH 7 a slight attack at the liquid surface and swelling below; (C) at pH 9 a liberal attack at the surface and swelling below; and (D) at pH 10 attack on the immersed portion and a greater attack at the solution surface.
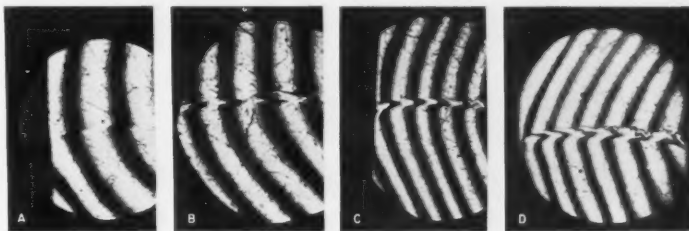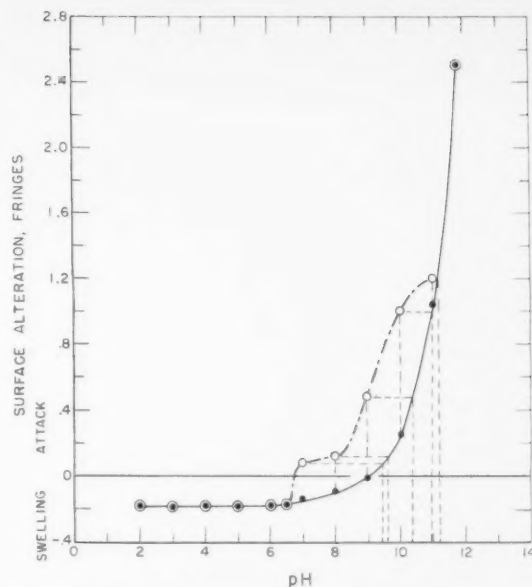

at controlled conditions of temperature and pH. After the desired length of exposure they were withdrawn, rinsed and dried, and covered with an optically flat piece of quartz. Using a conventional interferometric viewing apparatus, the displacement of the optical fringes at the liquid line and in the solution interior was observed. If the specimens were not attacked, the fringes were straight and continuous. However, if the immersed part of the specimen surface were attacked, each of the vertical fringes was shifted laterally. If the solution caused swelling of the specimen, the lateral shift was in the opposite direction.

This method also demonstrated the swelling of the glass in the bulk volume of solutions at pH 7 and the etching of the specimen at the surface of the same

liquid. The attack in the bulk volume and the attack at the liquid surface were then plotted over a pH range. These curves revealed, for example, that the attack at a solution surface at pH 7 is equal to the attack in the bulk volume of a solution at pH 9.4. This surface attack decreases rapidly at higher pH values, becoming nondetectable at pH 11.8. Unfortunately, because of the chemical durability characteristics of the glass, no differentiation could be made between the attack at the surface and in the interior of solutions more acid than pH 7.

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[1] The increased chemical reactivity of the surface compared with that in the bulk volume of Britton-Robinson universal buffers, by *Robert G. Pike and Donald Hubbard, J. Research NBS* **59**, 411 (*December 1957*) *RP2811.*

TABLE 1. *Difference in pH values producing equal attack at the surface and in the bulk volume of buffer solutions*

| Bulk volume alkalinity	Surface attack equal to that produced by bulk volume alkalinity	Difference
pH	pH	pH
7	9.4	2.4
8	9.6	1.6
9	10.4	1.4
10	10.9	0.9
11	11.2	.2
11.8	11.8	.0

Attack on glass in the bulk volume of a solution and attack at the surface of the same solution are plotted over a pH range. These results show that in the range pH 7 to 11.8 the attack at a solution surface is equal to the attack in the bulk volume of a solution of higher pH.

Prover for Liquefied Petroleum Gas Dispensers

TO ASSIST the States in maintaining uniform standards of measurement, the Bureau has developed equipment that checks the accuracy of devices dispensing liquefied petroleum gas (LP Gas).[1] This equipment takes the form of a volumetric prover which measures the liquid volume of LP Gas dispensed so that a precise comparison with the meter reading can be made.

Because liquefied petroleum gas does not remain in the liquid state when exposed to the atmosphere, State inspectors have not in the past had a uniform and completely satisfactory method of testing the accuracy of the liquid meters used commercially to measure this product. In recent years, as this fuel has come to be used more and more for home heating, automotive fuel, and industrial applications, the need for meter-
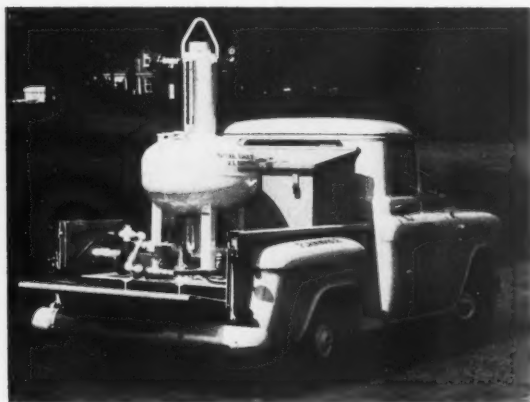
Prover (developed by the Bureau) to check the accuracy of meters dispensing liquefied petroleum gas. The prover, a closed system, consisting of a spheroidal tank with upper and lower glass-gage necks and appropriate gages, valves, and fittings is shown here mounted on a truck.

testing equipment has become more pressing. The various States (acting through the 42d National Conference on Weights and Measures) and members of industry requested the Bureau to design suitable equipment and to develop procedures for its use.

The prover designed for this purpose measures LP Gas in its liquid state by means of a large spheroidal tank equipped with upper and lower necks. Each neck has a gage glass and scale for reading the liquid level. The lower neck is small in diameter and is filled to its "zero" point before a volumetric test is begun. At the end of the test the total volume can be read from the scale in the upper neck. Because of the nature of the liquefied gas, the tank must be constructed to withstand very high internal pressures and must be equipped to facilitate the accurate reading of temperatures and pressures—conditions that affect the precision of the test. The prover can be either stationary or mounted

on a truck or trailer, and should have a capacity of at least 50 gal.

A volumetric test is made by pumping liquid into the prover until the dispensing meter indicates an amount equivalent to the nominal capacity of the prover. Since this liquid displaces vapor which would affect the volume if allowed to condense to liquid, an open vapor-return line to the supply tank is maintained. In this way difficult calculations and corrections are avoided.

About to begin a volumetric test of a meter on a LP Gas supply truck. The prover indicates the amount of product actually dispensed so that the meter reading can be checked.

So that an accurate comparison can be made between the volume in the prover and the volume indicated by the meter, certain conditions must be noted during the course of a run. As liquid is entering the prover the temperature at the meter is read at 20-gal intervals and the rate of flow determined. At completion of the filling, pressure and temperature in the prover are recorded. The actual amount of liquid in the prover can be read from the upper gage glass to the nearest 0.025 gal, and when this value is corrected for temperature and pressure differences, the error in the meter indication can be determined.

Experimental and demonstration test runs in seven States and at the Bureau have demonstrated the effectiveness of the prototype prover. Provers of this type are now being manufactured commercially and are being acquired by States and local jurisdictions.

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[1] *Copies of the recommended testing procedure involving the use of the prototype liquefied petroleum gas meter prover are available on request from the Office of Weights and Measures, National Bureau of Standards, Washington 25, D. C.*

Flow Capacities of Pneumatic Components

THE BUREAU has completed a Navy Bureau of Aeronautics sponsored program designed to formulate improved procedures for rating flow capacities of pneumatic components.[1] A satisfactory test method utilizing a dimensionless parameter was developed by D. H. Tsai and M. M. Slawsky of the thermodynamics laboratory in answer to requests of the aircraft industry, where pneumatic components find extensive application. Examples of airborne pneumatic operations are extending and retracting landing gear, lowering air brakes, emergency canopy or seat ejection, gun charging, and rocket ejection. The resulting concepts and procedures have been made available to the aircraft industry and to other fields where pneumatic devices are used.
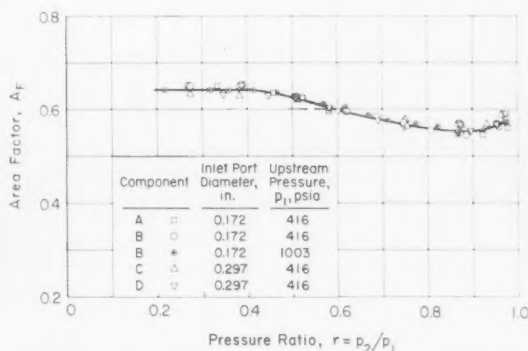
Correlation of flow data for pneumatic components by procedures developed at the Bureau. The curve of area factor, A_F ($=CA/A_{ref}$), versus pressure ratio, r, is seen to be identical for four similar components in two sizes.

The study of pneumatic components brought to light inadequacies in accepted testing practice and ambiguities in some basic concepts. In the past, flow capacity was specified in terms of the pressure drop across the component and was therefore dependent on the state of air passing through the valve. A dependence instead on the geometric construction of the valve would not only be more logical but would also make it possible to express the flow capacity in a dimensionless form. To satisfy this objective while still defining flow capacity in terms of conveniently measurable quantities such as pressure, temperature, and mass rate of flow, the Bureau suggested the use of an "area factor".

A similar consideration is employed in describing the capacity of a flow-metering nozzle. For such a nozzle, a "discharge coefficient" is usually defined as the ratio of the actual mass rate of flow through the nozzle to the mass rate of flow through an isentropic nozzle with the same minimum throat area under iden-

tical test conditions. The mass rate of flow of an isentropic nozzle, W_s, depends upon the parameters: Throat area, A; pressure, p_1, and temperature, T_1, upstream of the nozzle where fluid velocity is low; and pressure, p_2, at the throat of the nozzle. This relationship is expressed as

$$W_s = \frac{Ap_1\Phi(r)}{\sqrt{T_1}},$$

where $r = p_2/p_1$ and Φ is a function of r and the specific heats of the fluid. If the actual rate of flow through a nozzle of the same throat area A under conditions p_1, p_2, and T_1 is W, then the discharge coefficient, C, is W/W_s.

The advantage of using the discharge coefficient is that its value for a particular nozzle tends to remain constant over a wide range of test conditions. Also, since the discharge coefficient is dimensionless, it is independent of the size of the nozzle. Therefore, once it is determined for one nozzle under a given set of test conditions, the capacity of a series of nozzles geometrically similar to the test nozzle is immediately known independently of pressure and temperature relationships. The discharge coefficient is also a figure of merit because the mass rate of flow through an ideal, isentropic nozzle provides a convenient and valid reference for comparing the effectiveness of different nozzles as flow-handling devices.

Some difficulties arise in applying these considerations to the rating of pneumatic components. Because the flow passage in a pneumatic component is usually much more complicated than in a nozzle, it is often difficult to determine the pressures p_1 and p_2, temperature T_1, and minimum area A in the two cases. The difficulty with the area may be avoided by defining another dimensionless capacity in terms of the mass rate of flow through an isentropic nozzle of a reference throat area, A_{ref}. The choice of the reference area is somewhat arbitrary, the proper choice being largely a matter of convenience. For example, for a simple valve, the reference area may be taken as the cross-section area of the inlet port, and the physical meaning of CA/A_{ref}, which is equal to $W/[A_{ref}(p_1/\sqrt{T_1})\Phi(r)]$, is the ratio of the actual rate of flow through the valve to the maximum rate of flow through the inlet port alone, without friction or other losses.

The problems in the measurement of p_1, T_1, and p_2 are more serious because the difference between the flow patterns in the component and in the reference isentropic nozzle makes it difficult to specify test conditions which would correspond precisely to the conditions of the computed reference isentropic flow rate. Also, from a practical point of view, locating pressure and temperature probes in the actual component with-
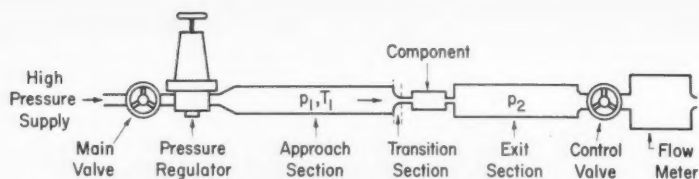
Schematic diagram showing the experimental setup used at the Bureau to measure flow capacity.

Transition pieces for the approach and exit sections of a test arrangement for rating pneumatic components. The nozzle-shaped transition piece (left) reduces entrance flow loss into the component. The exit-piece (right) allows the component to discharge abruptly into a larger pipe.

out altering the component in some manner may be impossible.

For these reasons, it is preferable not to insist on exact correspondence, but to specify other pressures and temperatures which could be measured more easily, and which would have comparable meaning for components of different designs and sizes. It is usually convenient to measure pressure p_1 in a large approach section which is connected to the inlet of the component through a short nozzle-shaped transition piece. Temperature T_1 is then taken as the temperature corresponding to p_1. Pressure p_2 logically should be the static pressure at the exit plane of the component. A convenient method for obtaining this pressure is to allow the component to discharge into a larger pipe through an abrupt change of section, and to take p_2 as the pressure in the dead-air region near the exit of the component.

Rating the capacity in terms of CA/A_{ref}, which may be called an area factor, therefore involves some arbitrary decision in the choice of A_{ref} and of the locations of the pressure and temperature probes. Because of this, the value of the area factor generally does not remain constant over a wide range of test conditions. If a single number is to be assigned to a component to indicate its capacity, the pressure ratio across the component would have to be specified also. Some of the advantage in the basic concept of the discharge coefficient C for a nozzle is thus lost when the area factor is used. Nevertheless, the area factor has been found to be a very useful parameter for correlating flow data of many flow-handling devices, such as pneumatic valves, compressors, and internal combustion engines.

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[1] A detailed description of the procedures developed by the Bureau is given in National Bureau of Standards Circ. 588, Determination and correlation of flow capacities of pneumatic components, available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. 10 cents.

Conference on Electronic Standards and Measurements

A CONFERENCE ON ELECTRONIC STANDARDS AND MEASUREMENTS will be held at the NBS Boulder Laboratories, Boulder, Colorado, on August 13 to 15, 1958 under the joint sponsorship of the American Institute of Electrical Engineers, the Institute of Radio Engineers, and the National Bureau of Standards. The conference will be devoted to new developments, techniques, and problems of measurements. It will also include the dedication of the new Electronic Calibration Center of the National Bureau of Standards. Inspection of the facilities of the Bureau's new operation should be of considerable interest to the Conference participants.

Today's vital interest in science and the ever-increasing need for instrumentation are a challenge for the improvement of standards and measurement techniques.

In no field is this challenge greater than in electronics, as witnessed by missile control, automation, electronic computing machines, radar, and navigation systems. The very complexities of these devices require that instrumentation and measurement techniques be based upon well-ordered systems of standards. To provide a means for interchange of ideas in this field on a National level, the AIEE, IRE, and NBS are sponsoring a conference during August of this year.

The 1958 Conference will be divided into six main sessions: Relationship of Standards to Physical Constants, Frequency and Time Interval Standards, Direct-Current and Low-Frequency Standards, Radio Frequency Standards, Microwave Standards, and the Organization and Operation of Standards Laboratories. More details will be published at a later date.

Reference Fuel Gas Available from National Bureau of Standards

CYLINDERS OF STANDARD GAS having a certified heating value may now be obtained from the Bureau.[1] This recently inaugurated service is the result of a cooperative research effort by the Bureau and the Research Committee of the American Gas Association to develop a reference gas, certification procedure, and calorimetric test methods acceptable to the utilities marketing natural gas as a fuel.

The tremendous increase in the use of natural gas as a fuel has focused attention on the need of a standard gas for the calibration of recording calorimeters[2] used to measure the heating value of natural gas and similar gas fuels. The accuracy of this instrument, which determines the daily or hourly quality of the gas at the source, is a matter of vital concern to the general consumer and the gas utility. The American Gas Association therefore initiated a general study with three specific objectives: (1) To evaluate the recording gas calorimeter; (2) to select a suitable reference gas having a heating value near that of natural gas; and (3) to develop a simple standards program to insure the availability of this standard gas to industry. The Bureau actively participated in all phases of this study and, in particular, directed the technical research activities of certification.

The program now in operation is essentially the same as that previously administered by the American Gas Association. The reference gas is supplied in standard "E" cylinders containing approximately 250 SCF (standard cubic foot for gas calorimetry) of gas at an initial pressure of about 1,900 psi, roughly sufficient for 200 calibrations. The gas has a certified heating value of approximately 1,000 Btu/CF. Charges for gas, tank rental, and services have been fixed so that the program is self-supporting.

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[1] Request forms and additional information can be obtained by writing directly to National Bureau of Standards, Chemistry Division, Washington 25, D. C.

[2] For further information on recording calorimeters, see Accuracy of the Cutler-Hammer recording gas calorimeters when used with gases of high heating value, by J. H. Eiseman and E. A. Potter (D. C. Gas Inspection Bureau) J. Research NBS 58, 213 (1957) RP2754.

New Plan for Advisory Committee Program

THE NATIONAL BUREAU OF STANDARDS and the National Academy of Sciences—National Research Council have announced an expanded plan for coordination of the Bureau's technical advisory committee program by the Academy-Research Council in cooperation with a number of the major professional scientific societies of the United States.

The National Academy of Sciences—National Research Council is a non-Government organization of the nation's leading research scientists dedicated to the furtherance of science and its use for the common welfare. It is specifically authorized by Act of Congress to advise the Federal Government, upon request, on matters of a scientific or technical nature.

The National Bureau of Standards advisory committee program grew out of the recommendations of a committee appointed by the Secretary of Commerce in 1953. Since that time, advisory committees appointed by various professional scientific societies have helped to keep the Bureau informed of the needs of the Nation's scientific and technological community and have evaluated the Bureau's work in areas of interest to their professions. At the same time they have provided an effective link whereby the scientists and engineers of the country have gained increased awareness of the scientific contributions and services available from the Bureau.

The new plan for coordination of these advisory activities by the Academy—Research Council will strengthen the current program by allowing more complete coverage of the Bureau's diversified research activities, and by providing for the coordination of recommendations from the various professional interests which the Bureau serves.

Under the new arrangement, the scientific societies will nominate representatives from among their membership to serve as advisors to the Bureau. From the base provided by these society delegations, the Academy—Research Council will assemble a number of advisory panels, each of which will have responsibility for evaluating a particular segment of the Bureau's work. Thus, certain Bureau activities, such as building technology which does not fall within the scope of any one professional society, can now be served by advisory panels staffed from various societies. The panels will report at least once a year on the status of Bureau activities under their cognizance. These reports will form the basis for an integrated annual report by the Academy—Research Council to the Bureau.

Selection of the National Academy of Sciences—National Research Council to administer and coordinate the advisory program will insure a broadly based, independent evaluation of the Bureau's work. Since it maintains well-established ties with the professional scientific societies of the country, the Academy—Research Council is uniquely qualified to assist the Bureau in this new role.

Initial nominations of advisory representatives will be made from the following societies: American Chemical Society, American Institute of Physics, Institute of Radio Engineers, American Ceramic Society, American Institute of Mining, Metallurgical and Petroleum Engineers, American Society of Mechanical Engineers, American Society of Civil Engineers, and American Institute of Electrical Engineers. The Policy Committee for Mathematics will nominate individuals from the various professional mathematics societies.

Cryostat for Precise Temperature Control Over Very Wide Range

THE CRYOGENIC ENGINEERING LABORATORY of the National Bureau of Standards Boulder (Colo.) Laboratories has developed in connection with a U. S. Army Signal Corps Engineering Laboratory project, a cryostat that is useful for low-temperature research concerned with the behavior of electronic elements such as a quartz-crystal-oscillator frequency standard.

By employing several convenient liquefied gases successively as refrigerants, the cryostat controls the temperature of an electronic element over a wide range of temperatures—at essentially any value between the boiling point of liquid helium and room temperature. The precision of control ranges from approximately 1 one-hundredth to 1 one-thousandth of a degree.

Although numerous cryostats for particular purposes have been described in technical publications, some additional design problems are posed in providing an easily adjustable control system for such a wide temperature range. A method must be provided for obtaining temperatures between those of the available liquefied gases. The system adopted by R. D. Goodwin of the Cryogenic Engineering Laboratory is analogous, in principle, to the operation of an ordinary household electric oven. A thermometer or thermostat in the oven automatically adjusts the electric heat input to balance exactly the heat loss to the cooler environment. The environment employed in the cryostat is at the very low but slightly variable temperature provided by a liquefied gas, such as liquid nitrogen, which is allowed to boil freely at atmospheric pressure. Thermal conduction between "oven" and environment is controlled by adjusting the pressure of a gas employed for heat transfer in the intervening space. The "oven" contains a thermometer and an electric heater. Manual adjustment of the gross level of heating determines how "hot" the cryostat "oven" will be compared to the liquefied gas refrigerant. Automatic control of the heating at this level maintains a constant temperature, despite small changes in the temperature of the liquefied gas environment or heat effects produced in the "oven" by test elements.

The cryostat employs electric resistance thermometers in electric bridge circuits which have been designed both for ease of adjustment over a wide temperature range and for optimum practical sensitivity per unit electric power developed in the thermometer, since the latter is a limitation upon resistance thermometers.[1] The maximum allowable change of temperature of the cryostat "oven" produces a useful signal from the resistance thermometer bridge of the order of 1 μv. Utilization of such a small signal for temperature control requires an electronic amplifier with a gain of about one million. The amplifier must not drift nor produce spurious signals (noise) greater than about one-tenth of a microvolt. The amplified signal then is applied to an electronic power regulator for control of the electric heating of the cryostat "oven".[2]

[1] Goodwin, R. D., Design of simple dc resistance thermometer bridges for wide-range temperature control, *Proceedings of the 1957 Cryogenic Engineering Conference* (Aug. 19, 1957) Boulder, Colo.

[2] Goodwin, R. D. and Purcell, J. R., Direct-coupled power amplifier for cryostat heating control, *Review of Scientific Instruments* 28, 581 (1957).

Photograph of cryostat developed by the Bureau for precise, wide-range temperature control. At right are the five disassembled concentric vessels. On the left is part of the pumping system, with valves and gages required for vacua and the handling of gases.
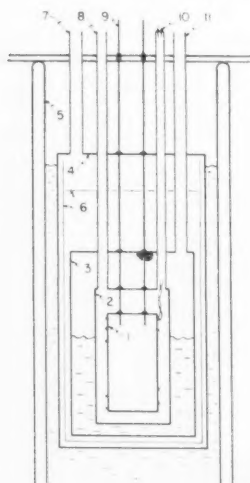
A schematic diagram of concentric vessels of the cryostat. "Oven" 1 is insulated by vacuum held in 2. The refrigerant contained in 3 is protected by vacuum container 4 and radiation shields 6. For the lowest temperatures in 3, heat leak is further reduced by a refrigerant contained in the Dewar vessel 5 as shown.
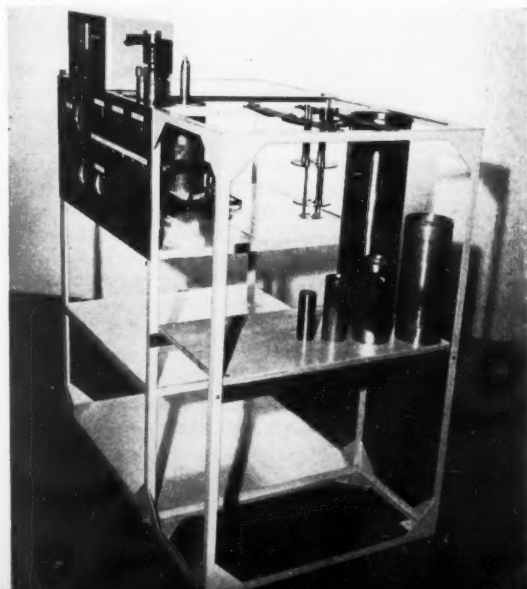
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